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SATELLITE OBSERVATIONS OF PARTICLE FLUXES AND ATMOSPHERIC EMISSIONS*

Part I: Summary of Relevant Particle Measurements Made from Satellites

Part II: Summary of Satellite Observations of Emissions

by

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SATELLITE OBSERVATIONS OF PARTICLE FLUXES AND ATMOSPHERIC EMISSIONS

Abstract. A survey is given of satellite-borne measurements of precipitated particles (in Part I) and of atmospheric emissions of light (in Part II). In Part I the survey shows that while there are increasingly comprehensive measurements of particle precipitation, the basic dynamical causes are still unknown and indeed it is difficult to formulate a definitive experiment in this regard. It is known, however, that there is "always" finite precipitation in the auroral zone (just as Part II shows that there is "always" some emission of auroral light) so that the unknown source must be continuously active. The latitude and diurnal variations of electron and proton precipitation are discussed in detail. Part II summarizes the satellite-borne photometric studies, which have been thwarted by vehicle failures in eight out of twelve studies. Preliminary results of airglow studies (all as yet unpublished) are presented. Principal results have been obtained to date in auroral studies rather than in airglow. Simultaneous measurements of auroral light and the particles exciting it are discussed. Technical advantages and disadvantages of satellite-borne photometry are listed, together with promising lines of future research.

PART I: SUMMARY OF RELEVANT PARTICLE MEASUREMENTS MADE FROM SATELLITES

1. INTRODUCTION

In this Symposium on Aurora and Airglow (so often linked like "Tweedledum and Tweedledee"), it is well to begin by distinguishing one phenomenon from the other. To quote Chamberlain [1961], "The most frustrating aspect of defining the airglow lies in distinguishing it from the aurora." One might adopt a simple approach that "If you can see it, it's an aurora; if you can't see it, it's airglow." But clearly this distinction fails with bright mid-latitude red arcs, with mantle auroras, and with daytime auroras, for example. Therefore, here I adopt a different distinction, and state that if the atmospheric excitation is due to direct bombardment of atmospheric constituents by non-thermal ("energetic") charged particles we should call it an aurora, (e.g., O'Brien, et al., 1965). Thus, in this first part, discussions of satellite observations of particle fluxes lead to a concentration of attention on the relation of those particle fluxes to auroras.

An historical review of the interrelation of particle fluxes and auroras has been given elsewhere [O'Brien, 1964(a)] and only a summary is presented here.

The first direct observation of "auroral particles" (i.e. the energetic particles that bombard the atmosphere to cause auroras) was made with rockoons by a group from the State University of Iowa [Van Allen, 1957]. The latitude distribution of counting rate of a geiger tube at an altitude of $\approx$100 km was found to have an "anomalous" increase around magnetic latitude $\lambda \approx 67^{\circ}$, i.e. in the auroral zone. This increase can now be understood as a statistically-prevalent zone of maximum intensity of "precipitated" electrons, i.e. those that plunge into the atmosphere from high altitudes.

During the same period, ground-based studies of Doppler-shifted Balmer emissions showed that, although protons with energies up to $\approx$100 kev bombarded the atmosphere during some auroras, they did not carry sufficient energy flux to sustain the auroral luminosity (see Omholt summary, 1963). McIlwain [1960] fired rockets into auroras, and showed that the brighter auroral displays are excited by bombardment by electrons with energy of $\approx$1 to 10 kev. The dominant problem then became - where do these electrons come from and how do they acquire their energy and other spatial and temporal characteristics?

With the discovery of the geomagnetically-trapped radiation with Explorer I [Van Allen, et al., 1958], auroral studies became intimately interwoven with satellite studies of energetic charged particles in the magnetosphere. The several historical developments in this relation have been discussed in detail elsewhere [O'Brien, 1964(a)] and they may be summarized as:

(a) discovery and study of particles in the "loss cone", i.e., precipitated particles [Krassovsky, et al., 1962; O'Brien, 1962];

(b) discovery that the flux of outer-zone trapped electrons was one thousand-times smaller than some previous estimates [Gringauz, et al., 1962; O'Brien, et al., 1962] and hence that the Van Allen zone was an inadequate reservoir or "leaky bucket" for auroral electrons, with later validation that if Van Allen and auroral particles were related at all, it was in the nature of a "splash-catcher" relation [O'Brien, 1964(b)];

(c) discovery of the high-latitude boundary of trapping, its local-time dependence, and its crude correspondence to the auroral zone [O'Brien, 1964(b)] and the discovery of the magnetopause in the equatorial plane [Freeman, et al., 1963];

(d) discovery of the "neutral sheet" in the extended magnetospheric tail [Ness, et al., 1964];

(e) experimental verification of the existence of the collisionless shock front in the equatorial plane [Ness, et al., 1964].

The charged particle environment of the earth is now known to be as sketched in Figure 1 although very little exploration has been carried out at the higher latitudes between altitudes of some 3000 km [O'Brien, 1964(b)] and 17 R_e [Bame, et al., 1966]. Here I will not embark on the important but very complicated problems posed by these particle distributions at high altitudes, nor deal with the problem of actually tracing auroral-zone field lines back into the equatorial plane to determine if they are "open" or "closed" [see Ness, et al., 1964; Taylor and Hones, 1964; Dessler and Juday, 1965]. Instead, I will concentrate on satellite measurements made near the "feet" of the magnetic field lines at altitudes between about 200 km and 3000 km. Thus, I will concentrate on the relation of these measurements to auroras on an "input-output" basis, and will only summarize some of the broader questions on the origins and causes of particle precipitation.

2. PARTICLE DYNAMICS

An energetic charged particle must hit the atmosphere in order to produce auroral luminosity. Since most auroras are brightest at an altitude of about 100 km, this altitude is usually chosen to define (somewhat artificially) a distinction between "trapped" and "precipitated" particles. Thus, trapped particles are those whose high-altitude trajectories are such that, without perturbation by atmospheric scattering but with conservation of their magnetic-moment invariant (μ) they would mirror (i.e., have pitch-angle $\alpha = 90^{\circ}$) at an altitude above 100 km. It is then assumed that they would thus have an appreciable probability of mirroring without any collisions, so that they would bounce back to the other hemisphere, i.e. be trapped. Precipitated particles are those that, with the above assumptions, would tend to mirror at altitudes below 100 km.

One can thus define a pitch-angle (α_D) at any altitude on a given line of magnetic force, such that particles with $0 \leq \alpha \leq \alpha_D$ are deemed to be precipitated, and those with $\alpha_D < \alpha \leq 90^{\circ}$ are trapped. One can calculate α_D at any point where the local field strength is B by making use of the magnetic-moment invariant which may be written (see review by Van Allen, 1963):

$$\frac{\sin^2\alpha}{B} = \frac{1}{B_m}$$

where B_m is the field strength at which the chosen particle trajectory would mirror. Then clearly

$$\frac{\sin^2\alpha_D}{B} = \frac{1}{B_{100\ km}}$$

Thus, for example, on the field line above the rocket range at Fort Churchill, $\alpha_D = 55^{\circ}$ at 1000 km altitude, while at 10,000 km it is about 14°, and in the equatorial plane it would be only about 2° if one assumed that the geomagnetic field was undistorted.

It is necessary to add words of caution on the artificiality of this loss cone, historically defined for electrons with about 100 kev energy. First, for precipitated electrons, there is a 10 to 20% probability of Coulomb backscattering from the atmosphere. Also, for low-energy (e.g. 1-10 kev) electrons the altitude of

100 km is actually below the altitude at which they are completely absorbed. The loss cone is therefore energy dependent. Furthermore, for energetic ions subject to temporary and repeated neutralization by charge exchange, the trajectories need to be calculated carefully to allow for the time spent as neutral atoms travelling unaffected by the Lorentz force and hence disobeying the magnetic-moment invariant (e.g. see Davidson, 1965). This effect leads to additional complications for alpha-particles since they can become He^+ as well as neutral He. For example, for 100 kev alphas even at the relatively high altitude of 250 km, only a few percent still retain two positive charges, with the remainder about an equal proportion of He^+ and He. Consequently, if one wishes to detect primary He^{++} energetic ions above an aurora with electrostatic-deflection devices, one must fire rockets or satellites to a far higher altitude than the nominal 100 km. Alternatively phrased, the loss cones for electrons and for such ions are not identical.

Another and particularly troublesome amendment to the above definition of a loss cone must be made in order to allow for localized magnetic [Cummings, et al., 1966] or electrostatic or other [Mozer and Bruston, 1966] effects. For example [see Cummings, et al., 1966] the localized distortion of the geomagnetic field near an auroral electrojet can lead to a localized "magnetic bottle" and other effects not treated in the above definition of a loss cone.

Nevertheless, this simplifying approach does permit quantitative intercomparisons of satellite, rocket and ground-based data, and we continue to follow it generally here.

3. ELECTRON AND PROTON PRECIPITATION

I will continue to concentrate here on satellite observations of particle precipitation, even though ground-based balloon - or rocket-borne instrumentation have in many cases given vital data impractical to attain with satellites that move across auroral structures with velocities of some 7 km/sec. Reviews of balloon-borne measurements have been given recently by Anderson and Milton [1964] while rocket studies have been summarized by Cummings, et al., [1966], and Mozer and Bruston [1966] and in several papers at this Institute. A general related review has been given by Hultqvist [1964], who tabulated experimental studies.

The early satellite measurements of precipitated electrons were somewhat hindered by relatively primitive instrumentation in the most important electron energy range, viz $1 \lessapprox E_e \lessapprox 10$ kev (see McIlwain, 1960). Consequently, the early ($\approx$1962-1964) studies were most concentrated on electrons with energy $E_e \gtrapprox 40$ kev, as detected by thin-windowed (1.2 mg cm^{-2}) geiger tubes (see, for example, O'Brien, 1964(a); McDiarmid and Burrows, 1965; also Mann, et al., 1964).

An extensive summary of these studies was given by O'Brien [1964(b)] and Figures 2 and 3 are taken from that summary. In general, that survey showed, for electrons with $E_e \gtrapprox 40$ kev at $\approx$1000 km altitudes that

(1) the flux of locally trapped or quasi-trapped particles <u>increased</u> above auroras so as to maintain approximate isotropy over the upper hemisphere (see Part II, O'Brien, in this Symposium); (Whether such isotropy persists for all energies and at higher altitudes is one of the presently-unsolved major problems.)

(2) the average world-wide energy dissipation by particle precipitation in the auroral zones is $\approx 4 \times 10^{17}$ ergs sec^{-1} or about 1% of the average energy brought by the solar wind to the front of the magnetosphere, with an average auroral zone deposition of a few ergs $cm^{-2} sec^{-1}$;

(3) the precipitated flux varied by a factor of more than 10^6 in time and space near the auroral zone (see Figure 3) although no property of the solar wind is known to vary by this amount;

(4) there is "always" precipitation and "always" an aurora (see O'Brien, Part II in the Symposium) near the auroral zone, so that the unknown source must be continually active. (Early theories were concerned mainly with the "great" auroras that follow large solar disturbances whereas recent theories have treated the continuous aurora, being encouraged since the solar wind and magnetosphere rotation are continuously present also);

(5) the night-time auroral zone as found by photometers lies near the high-latitude boundary of trapping, although whether it is inside or outside or straddling the boundary is presently unknown (simply because particles with $\alpha \approx 90^o$ above auroras may not be truly trapped in the stable magnetosphere, but one cannot examine this problem satisfactorily with a single satellite).

McDiarmid and Burrows [1965] have drawn attention to the fact (not evident here in Figure 3) that there are occasionally extremely intense "spikes" in space of electrons with $E_e \gtrsim 40$ kev inside the polar cap, i.e. at latitudes higher than the so-called boundary of trapping.

Other early satellite studies include the detection with Injun 1 of the most intense natural flux yet found by a satellite, viz, some 2000 ergs $cm^{-2} sec^{-1}$ of electrons with energy $E_e \gtrsim 1$ kev [O'Brien and Laughlin, 1962]. It is interesting to note that in spite of many years of high-altitude measurements, no comparably intense fluxes have been found near the equatorial plane. Since these fluxes, if isotropic in the equatorial plane, could not be contained or guided by the ambient magnetic field of some tens of gammas [cf. McIlwain, 1960] it is possible that if they occur in the equatorial plane at all (a point not yet proven) it may be that they occupy such a small solid angle (say around $\vec{B}$) that spinning satellites with directional detectors would sample them inefficiently, if at all.

McIlwain [1960] drew attention to the fact that the energy spectra of auroral electrons were much softer than those of electrons then observed in the near-equatorial plane. This experimental difference has now largely disappeared as probes have reached out with refined instrumentation to some 12 to 30 R_e. Studies such as those by Konradi [1966] and by Bame, et al., [1966] (see Figure 4) in these regions find electron spectra not clearly distinguishable from some of those found in auroras. Thus, although the <u>intensities</u> found to date in the equatorial plane are not as large as found in auroras, this may be largely due to experimental limitations mentioned above rather than to the lack of an interrelation.

The most definitive satellite studies of both electron and proton precipitation have been carried out in several short-duration (few days') flights by the Lockheed group. Their "Input-Output" studies have been presented at this Symposium already by Johnson and Meyerott, and I concentrate here more on their particle measurements alone.

One of the most dramatic findings is that of two separate zones of electron precipitation on the dayside (Figure 5). Lower-energy electrons ($0.08 \le E_e \le 21$ kev) were observed around magnetic latitudes 75°N, while higher energies were found around 69°N [Johnson, et al., 1966; see also Fritz and Gurnett, 1965]. This finding strengthens the conclusion of O'Brien [1964(b)] that the high-latitude boundary of trapping and the auroral zone are at much the same location. O'Brien's [1964(b)] data were based on his simultaneous observations of auroral luminosity and particle fluxes and were confined to local night. However, in 1961, O'Brien [1963] found that the high-latitude boundary of trapping was at invariant latitude $\Lambda \approx 69^\circ$ at night and at $\Lambda \approx 75^\circ$ in the day during magnetically-quiet conditions. The data of Johnson, et al., [1966] therefore extend this interrelation of auroral zone and boundary of trapping to the day-side also. Unfortunately, its theoretical implication is still not exactly understood, although a magnetospheric model such as that of Dessler and Juday [1965] would lead to such an interrelation.

The Lockheed findings of a "hard" and "soft" daylight zone also serve to resolve a controversy about the applicability of O'Brien's [1964(b)] finding to the dayside. It was pointed out (e.g. by N. Brice at the NATO Advanced Study Institute on Radiation Trapped in the Earth's Magnetic Field, Bergen Norway, August 1965) that peak daytime auroral disturbance (e.g. as measured by riometers) is at $\Lambda \approx 65^\circ$ rather than at the daytime boundary of trapping of $\Lambda \approx 75^\circ$. Since riometers respond most efficiently to harder electrons such as those in the lower-latitude zone found by Johnson, et al., [1966], this discrepancy is removed.

Extensive studies of precipitation of low-energy protons have been made most recently again by the Lockheed group [Sharp, et al., 1966; Sharp, et al, 1964; and Johnson, et al., 1966] and earlier by Mihalov and Mozer [1963].

During a 2 1/2 day period of magnetic quiet, Sharp, et al., [1966] found proton fluxes over northern and southern auroral zones with a peak of about 0.3 ergs $cm^{-2}sec^{-1}$. The spectra appeared crudely consistent with exponential forms with e-folding energies of some 10 to 20 kev, and the angular distributions appeared "consistent with isotropy over the loss cone to a factor of about two." With relatively few statistical samples two distinct daytime zones were found with maximum intensities at invariant latitudes $\approx 70^\circ$ and 77°, to be contrasted with the single nighttime maximum at about 68°. Such zones of proton precipitation may be compared with electron precipitation discussed above (see Figure 5).

Such bimodal daytime zones are worthy of considerable theoretical attention. First-order approaches that invoke differences in longitudinal drifting of particles mirroring at low and high altitudes are being adopted by numerous workers, and other complex trajectory studies are being made (e.g. see Taylor and Hones, 1965), and it seems possible that in such studies lie answers to the fundamental questions, viz

(a) where were these "auroral particles" ten seconds ago, or a day ago?

(b) how did they acquire their energy?

(c) how were they precipitated and what happened to them on the way?

One associated problem that is receiving attention from the Rice University group is a photometric and rocket-borne experiment to seek alpha-particles in primary auroral fluxes, thus using the p/α ratio as a "tracer" to determine the source of these ions.

The Lockheed group [Evans, et al., 1966] has made the very important simultaneous observations of low energy protons and electrons over the auroral zone. They found (Figure 6) that precipitated protons bring into the atmosphere an appreciable proportion (some 10 to 20%) of the total input from electrons and protons.

One of the most important measurements of auroral electrons is a determination of whether the differential energy spectrum has a pronounced maximum at a finite energy (say 1 kev). Such a condition could lead to growth of plasma instabilities (I am indebted to Dr. C. McIlwain and Mr. R. LaQuey for stimulating speculations on this problem). Unfortunately, it is not yet clear (from any experimental measurements known to me) that such a condition occasionally prevails. Threshold-type detectors which measure integral fluxes are inadequate to resolve this important matter, and differential instruments flown to date have had experimental uncertainties sufficiently large to obscure resolution of this matter. I regard this as one of the must urgent experimental problems to be resolved conclusively, and hopefully at various pitch angles above an aurora.

Generalizations about characteristic energy spectra and time variations are difficult to make because each parameter is itself greatly variable with time and space. In any event, as yet only balloon-borne and some rocket-based studies have definitively demonstrated the existence of significant temporal variations (see Anderson and Milton, 1964) and their significance is not yet understood. Similarly, the significance of the widely-variable energy spectra is not yet understood.

There is indeed a singular lack of coherence in any discussion of the above parameters. Such coherence may ultimately come from one of two sources:

(a) an exhaustive and very comprehensive experimental study of several auroral events, or

(b) from theoretical analysis of the causes, transportation and effects of such particle fluxes.

Both these approaches are likely to take a considerable amount of time before there is a significant "break-through" in our comprehension of the particle dynamics involved in auroral phenomena. Indeed, one of the major problems in studies of particle precipitation is not so much the implementation of an experiment, but rather the very formulation of what is a truly definitive and conclusive experiment.

4. ACKNOWLEDGEMENTS

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FIGURE CAPTIONS

Figure 1: Sketch of particle-environment domains in the vicinity of the earth.

Figure 2: Comparison of the dependence on K_p (the planetary magnetic disturbance index) of the maximum flux of precipitated electrons and the maximum flux of trapped electrons with $E_e > 40$ kev, where "maximum" pertains to a survey over all L values at $L > 3$ (after O'Brien, 1964(b).

Figure 3: Latitude distribution of flux of precipitated electrons with $E_e > 40$ kev (after O'Brien, 1964(b). Note that the variations at a given latitude are real variations in time, since the statistical or sampling errors are negligible.

Figure 4: Electron energy spectra found at 17 R_e in the tail of the magnetosphere (from Bame, et al., 1966).

Figure 5: Location of auroral zones as defined by precipitation of electrons and protons during both day and night (after Johnson, et al., 1966).

Figure 6: Comparison of total energy deposited in the atmosphere by precipitated electrons and protons (after Evans, et al., 1966).

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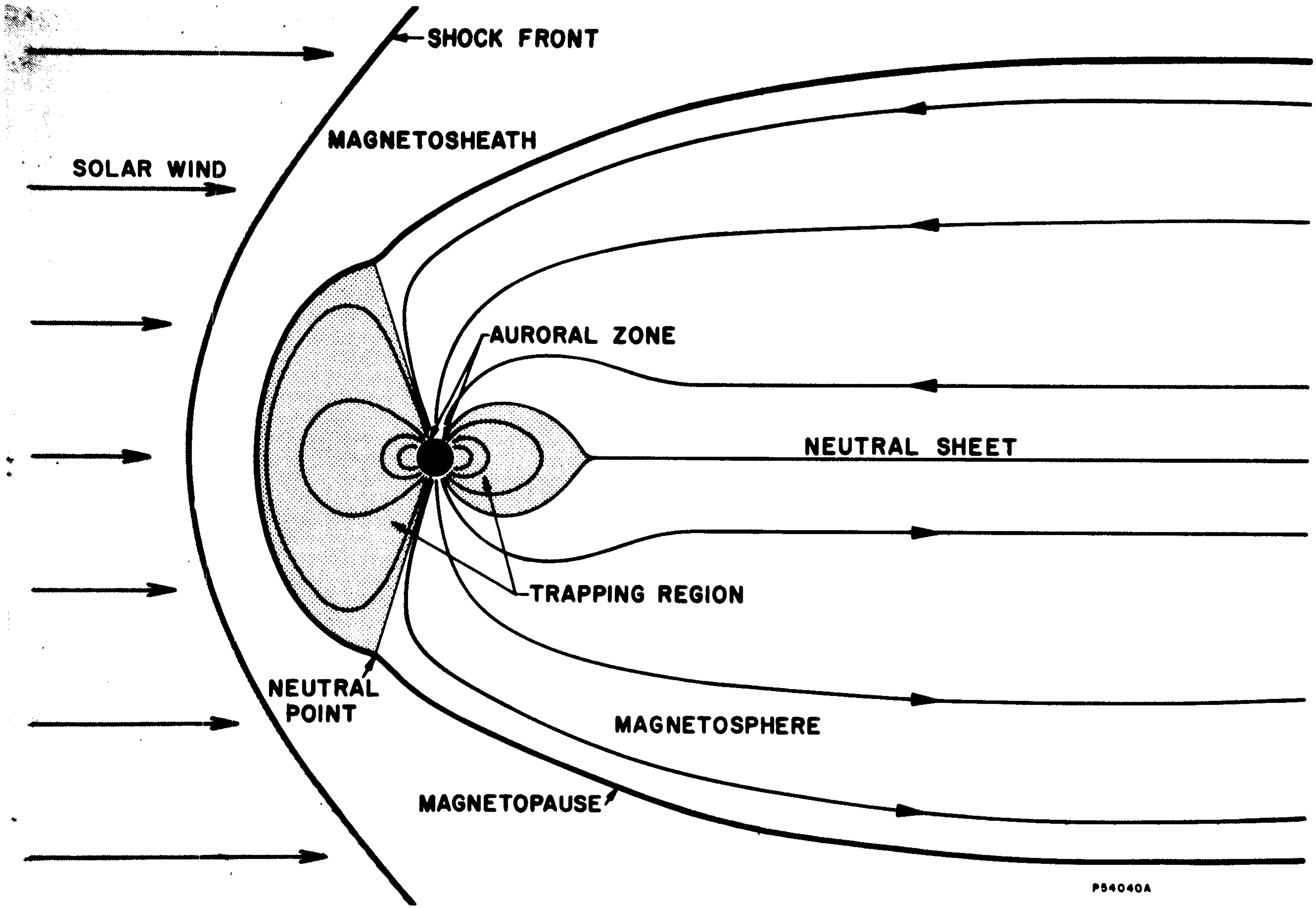

SHOCK FRONT
MAGNETOSHEATH
SOLAR WIND
AURORAL ZONE
NEUTRAL SHEET
TRAPPING REGION
NEUTRAL
POINT
MAGNETOSPHERE
MAGNETOPAUSE
P54040A

FIGURE I - 1

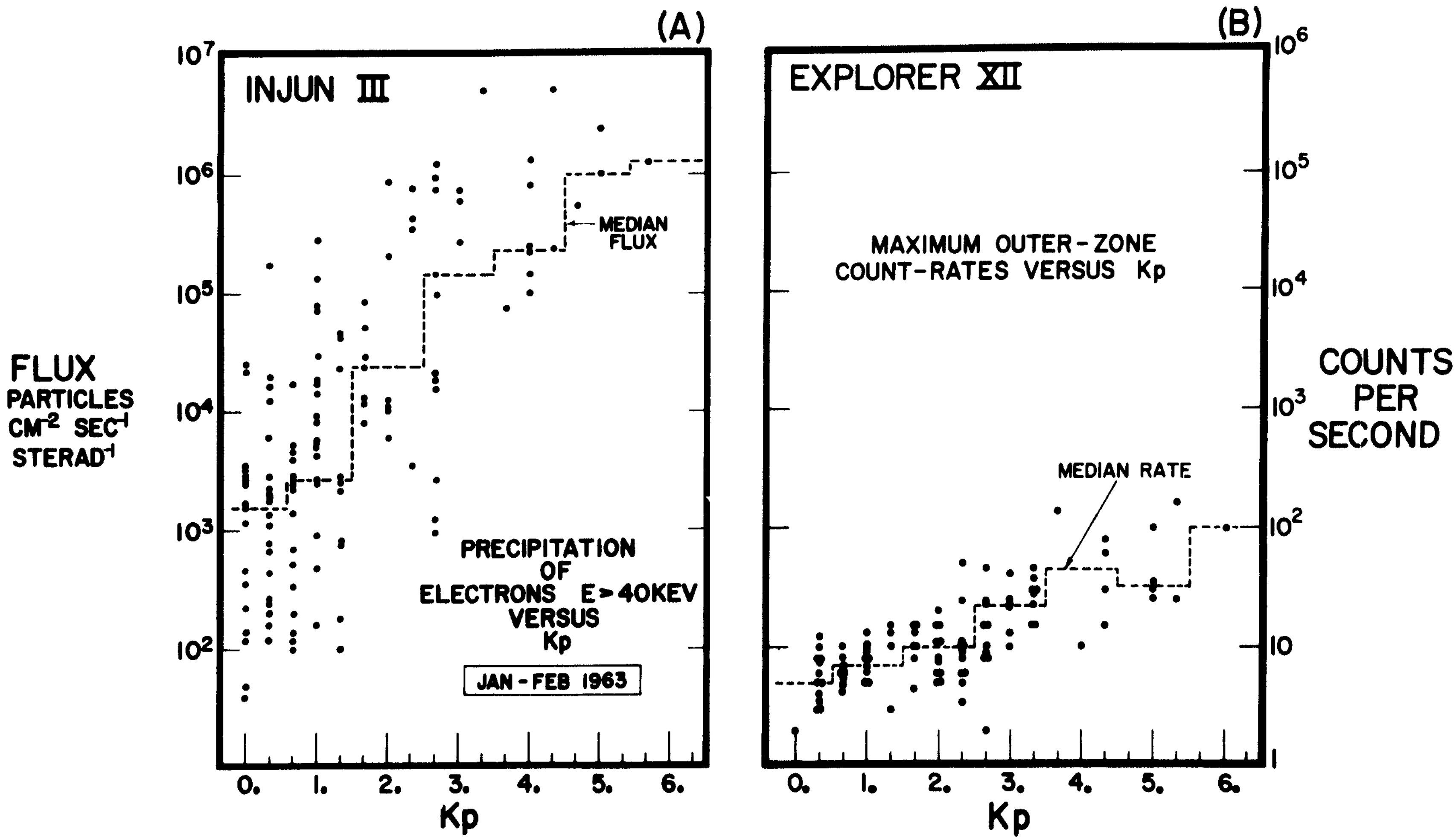

(A)
INJUN III
MEDIAN FLUX
PRECIPITATION OF ELECTRONS E>40KEV VERSUS Kp
JAN - FEB 1963
FLUX PARTICLES CM^{-2} SEC^{-1} STERAD^{-1}
10^7
10^6
10^5
10^4
10^3
10^2
0.
1.
2.
3.
4.
5.
6.
Kp
(B)
EXPLORER XII
MAXIMUM OUTER-ZONE COUNT-RATES VERSUS Kp
MEDIAN RATE
COUNTS PER SECOND
10^6
10^5
10^4
10^3
10^2
10
1
0.
1.
2.
3.
4.
5.
6.
Kp

FIGURE I - 2

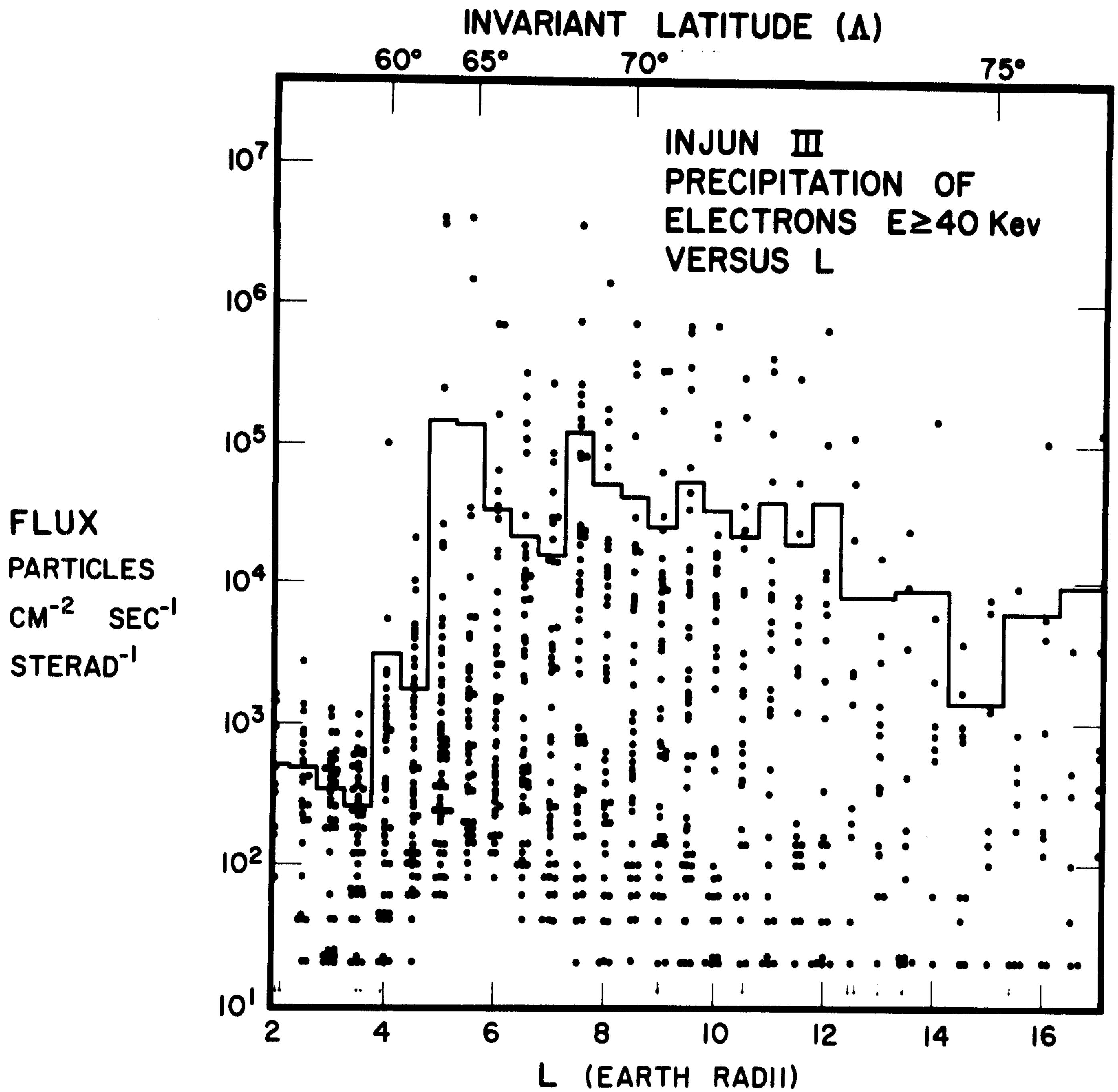

INVARIANT LATITUDE (Λ)
60° 65° 70° 75°
INJUN III
PRECIPITATION OF
ELECTRONS E≥40 Kev
VERSUS L
FLUX
PARTICLES
CM⁻² SEC⁻¹
STERAD⁻¹
10⁷ 10⁶ 10⁵ 10⁴ 10³ 10² 10¹
2 4 6 8 10 12 14 16
L (EARTH RADII)

FIGURE I - 3

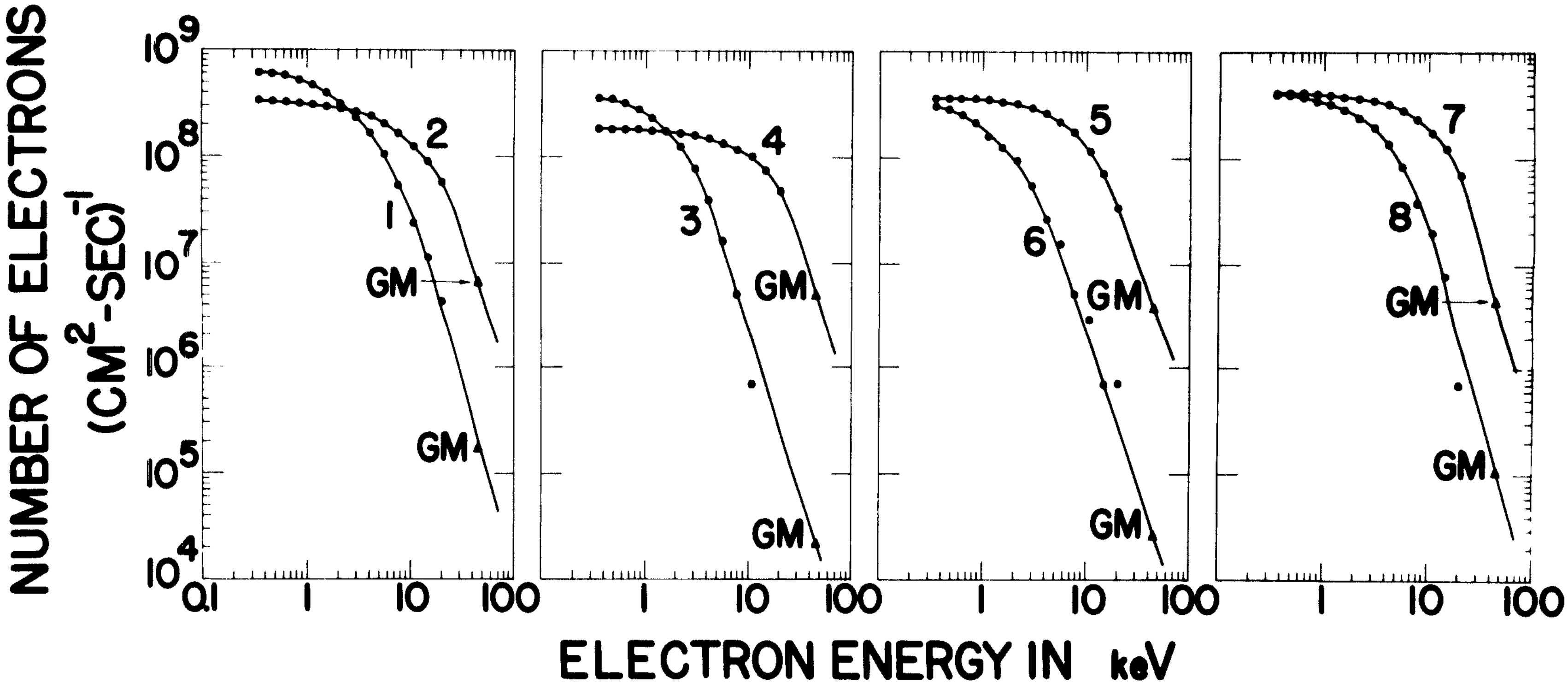
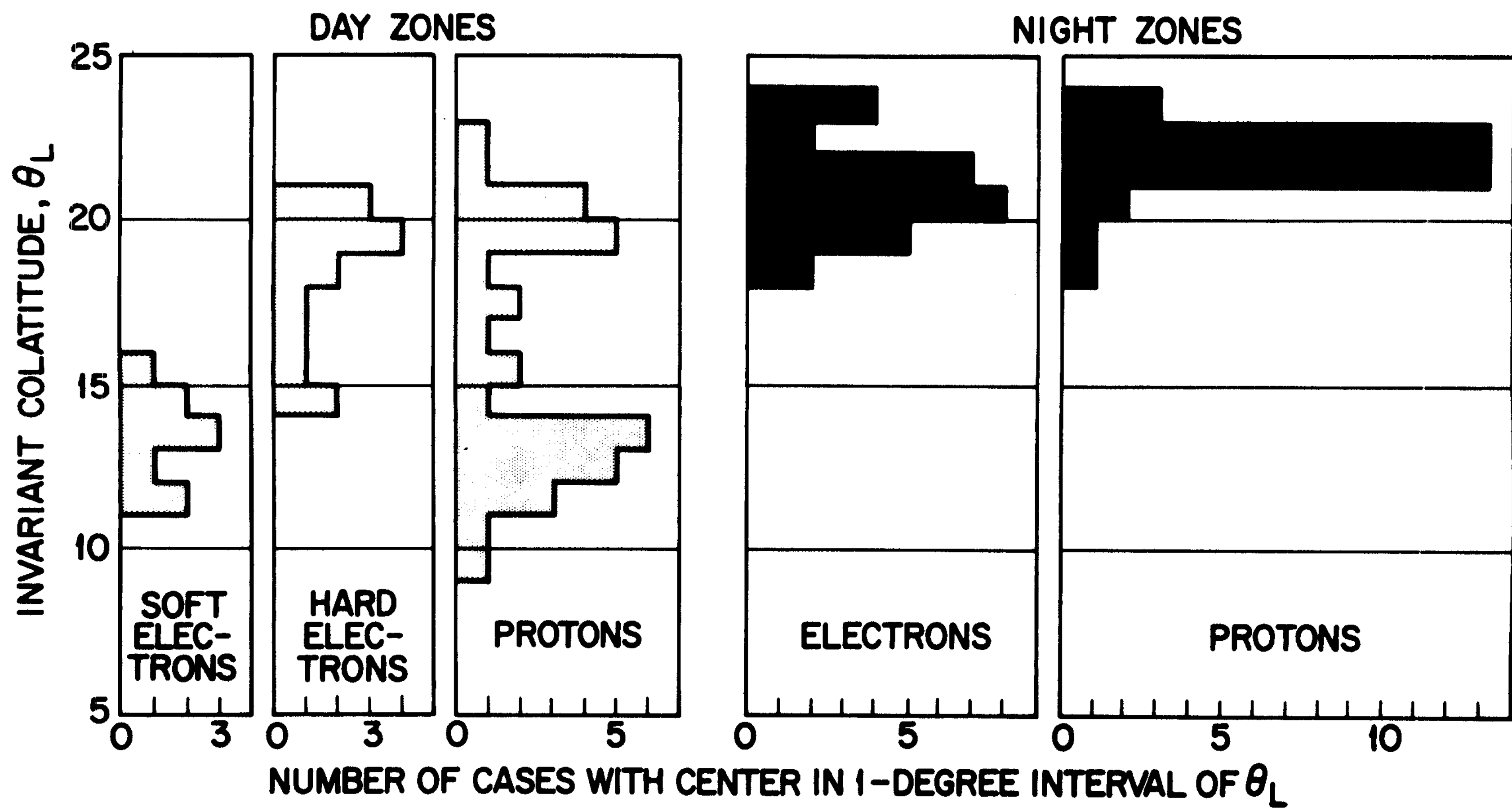

NUMBER OF ELECTRONS
(CM2-SEC)-1
10^9
10^8
10^7
10^6
10^5
10^4
0.1
1
10
100
1
2
GM
GM
3
4
GM
GM
5
6
GM
GM
7
8
GM
GM
ELECTRON ENERGY IN keV

FIGURE I - 4



LOCATION OF AURORAL ZONES–NOV. 9–10, 1965
PRELIMINARY ANALYSIS

FIGURE I - 5

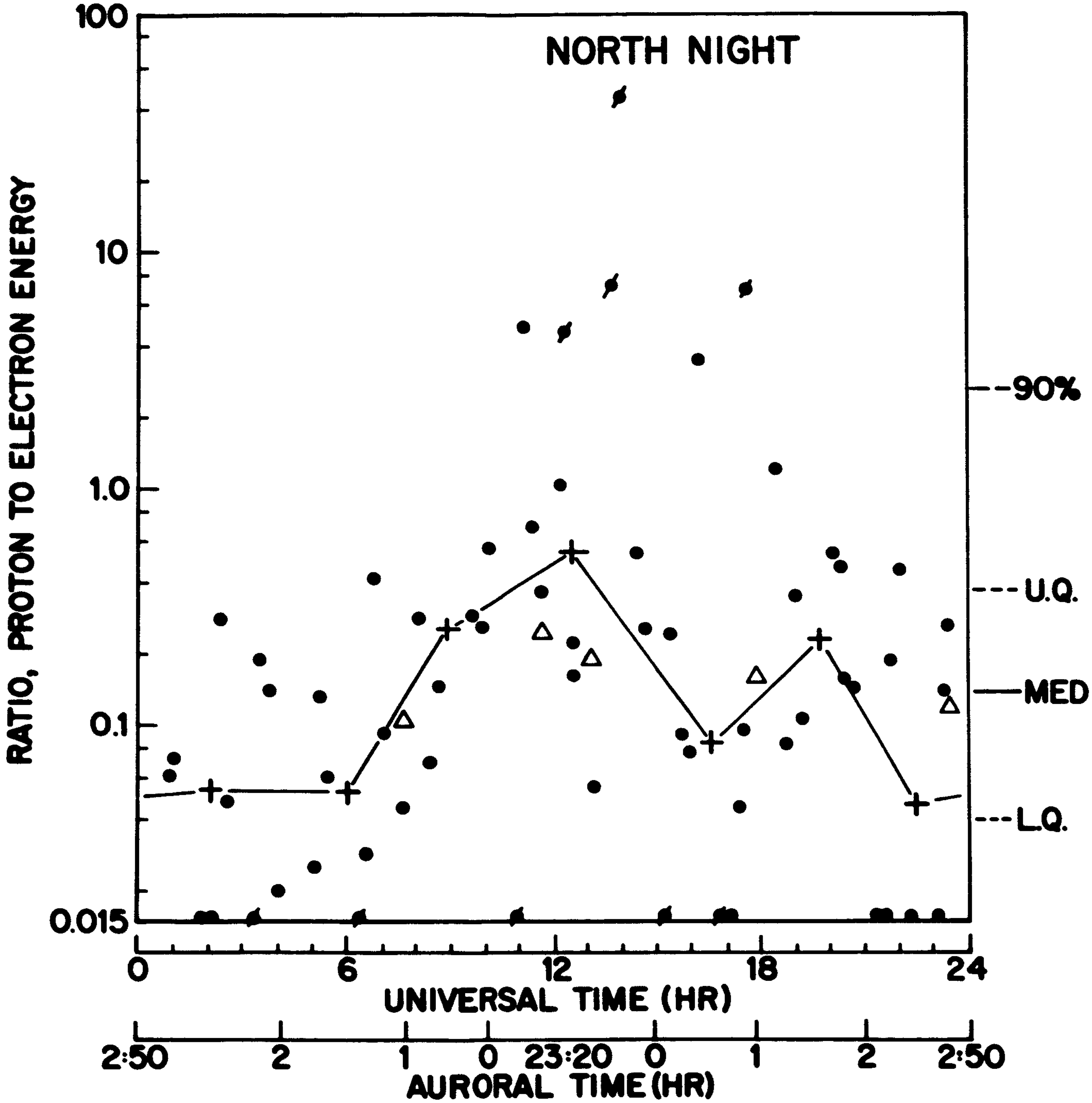

NORTH NIGHT
100
10
1.0
0.1
0.015
RATIO, PROTON TO ELECTRON ENERGY
--90%
---U.Q.
—MED
---L.Q.
0
6
12
18
24
UNIVERSAL TIME (HR)
2:50
2
1
0
23:20
0
1
2
2:50
AURORAL TIME (HR)

FIGURE I - 6

PART II: SUMMARY OF SATELLITE OBSERVATIONS OF EMISSIONS

1. INTRODUCTION

Satellite or spacecraft observations of airglow and aurora emissions are relatively few in number if one excludes the manned spacecraft studies. Relevant measurements from unmanned spacecraft are listed in Table I. Several visual and instrumental studies of airglow have been made by U.S. astronauts [cf. Gillett, et al, 1964] with principal findings relating to the height of the 5577A airglow emissions. There have been press reports of auroral observations by the USSR Cosmonauts in their higher-inclination orbits, but I know of no published scientific papers.

It is useful to summarize the reasons why one should trouble to make airglow or auroral observations from a satellite as distinct from the ground. (I regard short-duration rocket-borne measurements here principally useful as exploratory probes rather than for systematic morphological studies).

Satellite-borne measurements have the following advantages:

(a) they are made with no obscuring clouds and little absorbing or scattering atmosphere between the emission layer and the detector. Thus, one can study visible emissions with cloud-cover only a second-order problem (because of varied albedo) and one can study, for example, ultraviolet emissions at $\lambda \lesssim 3800A$ which are absorbed at lower altitudes by ozone, etc. so that a ground-based instrument cannot measure them.

(b) as a consequence of advantage (a) one can easily study daytime auroras by measuring UV emissions where an aurora is bright but albedo and rayleigh scattering are weak, i.e., where the sunlit earth appears black. Suitable spectral ranges are ≈1400A to ≈1800A. (This suggestion was first mentioned to the writer by Dr. F. Roach in 1961).

(c) A satellite can rapidly make spatial surveys, particularly useful over uninhabited regions.

(d) Particle detectors and other devices on a magnetically oriented satellite can be combined with photometers to measure both auroral cause and effects (see Figure 1, [O'Brien and Taylor, 1964]) or "input-output" effects [Johnson and Meyerott, this Symposium]. The logistic problems for the alternative approach using just particle detectors on a satellite and photometers on the ground was found to be relatively severe [O'Brien, et al., 1960].

(e) The satellite orbit, being essentially fixed in inertial space and hence temporarily fixed in local time, can be utilized, e.g., to test hypotheses such as the one that auroral structures are more-or-less fixed in local time.

Satellite observations of emissions do have unique potential sources of contamination, as summarized by O'Brien and Taylor [1964]:

1. By sunlight scattering off the atmosphere of parts of the satellite.
2. By similar moonlight effects.
3. By reflection from the earth (variable depending on surface).
4. By lightning.
5. By man-made lights.
6. By X-ray bombardment of the photometers producing enhanced "dark" current.
7. By heating of the photometers producing enhanced dark current.

Experimental techniques to minimize these effects were presented by O'Brien and Taylor [1964]. An additional problem is the quantitative correction necessary because of variable albedo of the emission itself. We estimate that this sets an upper limit of ±20% to the absolute accuracy of satellite observations. Historically, a far more serious problem seems to have been that the gods frown on photometric studies from satellites. For example, the 5577A photometer on Injun 1 operated perfectly for about 18 months, but its field of view was blocked by a highly-polished aluminum satellite, Greb, because a separation system failed [O'Brien and Taylor, 1964]. Injun 2, with 5577A and 6300A photometers, was plunged into the ocean in January 1962 due to a rocket failure. Elliott and his colleagues of Aerospace Corporation have attempted photometric studies with four satellites that - one after the other - - sank into the ocean, [Elliott, private communication]. The observatory POGO or OGO-II was orbited satisfactorily, but its sophisticated orientation schemes failed and only about 2 hours of useful eclipsed data were acquired [Reed and Blamont, 1966]. Consequently, a summary such as this note illustrates the major disadvantage of satellite studies of aurora and airglow emissions, viz, only four (4) successful launches out of twelve (12) attempts known to us.

2. AIRGLOW AND DAYGLOW

Manned spacecraft data indicate an airglow layer some (24 ± 3)km thick with an altitude varying between 77 km and 110 km [Gillett, et al., 1964]. The principal result of importance was that the altitude of peak emission appeared to show a real variation in space. This is a problem of very great interest insofar as it bears on the chemical causes of airglow but it is a problem unresolvable by ground-based studies because of the inherent problems in the Van Rhijn technique, and unresolved by rocket flights (e.g. Packard, 1961; Tavasova and Slepova, 1964; Nagata, et al., 1965; and O'Brien, et al., 1965) because of cost and related factors that limit the number of flights.

Manned spacecraft [Gillett, et al., 1964] and OSO-B data [Ney, private communication] also appear to show that there is no dust layer of appreciable opacity at the airglow layers.

The photographs made from manned spacecraft [Gillett, et al., 1964] also clearly indicate lightning strokes that can appreciably contaminate satellite studies. Elliott, [private communication] mentions that for part of his data the "satellite track followed a weather front and the spurious signals correlated with the weather station reports of lightning activity."

There are no published airglow data from unmanned spacecraft that as yet add materially to information collected from the ground. There is general support of the well-known general characteristics such as:

(a) 5577A airglow displayed an absolute minimum at the equator, [Elliott, private communication].

(b) Airglow in the green and blue displays a patchiness, with an intensity variation of less than some 250%, [Ney, private communication].

(c) 6300A emission rate varied in the nightglow $\approx$25 to $\lessapprox$ 1 photon cm^{-3}sec^{-1}, while in twilight it was typically 20 to 50 photons cm^{-3}sec^{-1}, [Reed and Blamont, 1966].

(d) The airglow 5577A intensity is roughly the same at latitudes just above and below the auroral zone (e.g. see Figure 7 of O'Brien and Taylor, 1964).

To date, five years' of these satellite measurements known to me have yielded relatively little. However, it may be expected that further satellite studies will contribute new and original data to the study of airglow. For example, the UV spectrometer and an ion chamber are measuring mainly the interesting dayglow emissions at 1216A and 1304 A, [C. Barth, private communication and P. Mange, private communication].

3. AURORAL DATA

Satellites have been much more fruitful in studies of auroral phenomena. Their particular utility is in cause-and-effect or input-output studies (e.g., see Figure 1) where they have the advantage over ground-based measurements that detect only the "effects" or the "output", e.g. of auroral light.

In Figure 2 is plotted the simultaneous observation of an aurora and its cause as determined from the magnetically-oriented satellite Injun 3 [O'Brien and Taylor, 1964]. Numerous other detectors and a VLF experiment gave correlated data not shown in this figure. Many such observations validated the concept of the "splash-catcher" model, wherein it was stated that, <u>if</u> Van Allen and auroral particles are related at all, it is only in the sense that both may have a common cause, rather than in the sense that the first category is the origin of the second (e.g., see O'Brien, 1964). Furthermore, this measurement established directly for the first time on an event-by-event basis, the very important association between the boundary of trapping and the auroral zone (see O'Brien, Part I, this Symposium).

From some fifty night-time passes of Injun 3 (see Figure 3), profiles of intensity of 5577A and 3914A were derived [O'Brien and Taylor, 1964]. Comparisons were made, for example, between the latitude profile of the mean 5577A intensity and the classical Vestine and Sibley [1959] "auroral zone" of <u>probability</u> of visible auroras (Figure 4). A rather more useful graph (Figure 5) shows the very important fact that in the first few months of 1963 there was a continuous emission of N_2^+ 3914A in the auroral zone. Since the energy of excitation of this emission is some 19 ev, it is generally agreed that its emission at night requires a source of energetic radiation, e.g., auroral particles, cosmic rays, X-rays, etc. [see O'Brien, et al., 1965]. From this it was concluded that auroras are continuously present in the auroral zone, albeit occasionally with less than the threshold of visibility [O'Brien and Taylor, 1964]. Accordingly, the source of auroral particles must be continuously active. This was verified by the same satellite [O'Brien, 1964].

The Injun 3 data on 3914A emissions were also used to derive the average total energy deposited by auroral particles in the earth's atmosphere and comparisons were again made with direct measurements of the particles with the same satellite (see O'Brien Part I, this Symposium).

Evans, et al., [1966] have obtained information on both 3914A emission and middle UV ($\approx$1600A) auroral emissions. Several cases were found in which the intensity in each band was comparable, but in other cases the UV intensity was considerably greater than that of the 3914A. The Lockheed group is currently studying particle-flux interrelations and characteristics that might lead to such real changes [Evans, private communication].

In an earlier experiment, the Lockheed group made a satellite measurement of particle fluxes and compared this with ground-based measurement of the auroral light [Sharp, et al., 1964]. The combined study indicated that, in at least one rather unusual auroral form and in the regions of low-level luminosity outside of discrete forms, electrons of energy less than a few kev carried an appreciable fraction of the precipitated energy.

Reed and Blamont [1966] obtained photometric data from a few passes over the northern polar cap, during relatively quiet geomagnetic conditions (0321 and 1347 UT, October 23, 1965). Using as a first approximation the relatively crude assumption that the auroral emission was in uniform horizontal layers, they were able to deduce the altitude distribution of the emission of 6300A. In particular, they found that the evening (1700 hours local time) sunlit aurora had peak emission at 250 km, while the morning aurora

(0400 hours) had peak emission at some 200 km. Further examples and information on the actual horizontal distributions will be needed to validate this interesting finding.

In general, it may be concluded then, that satellite studies of auroral emissions have already provided uniquely valuable data. However, I suggest here again that the potential value of such studies has not yet been realized, in large part because of the ill-fortune mentioned above.

4. FUTURE STUDIES

It seems appropriate to mention briefly some of the research problems that currently await satellite-borne measurements of auroral and airglow emissions.

Television photography of auroras is essentially within the state-of-the-art, and it is planned to fly sensitive vidicons on the magnetically-oriented Rice University/NASA satellites code-named OWLS in the fall of 1967. The particular applications in this project are:

(a) to study conjugacy of auroral forms

(b) to study auroral morphology (e.g. to examine their local time dependence, the occurance or multiple arcs, etc.)

(c) to relate the TV snapshots to data from numerous photometers and particle detectors on the same satellites.

It may be useful to note here that if the Owls and their TV operate successfully, then each will be able to provide once per week for interested auroral researchers, details and photographs of auroras in the area magnetically-conjugate to each auroral observatory.

On this same point of collaboration, it is planned to orbit in the fourth quarter of 1966 a Rice University/ONR satellite code-named "Aurora 1". This magnetically oriented satellite will carry a particle detector to make in the northern hemisphere differential and integral spectral measurements of precipitated electrons and protons with energy of some 50 ev and 150 kev. Photometers will measure four auroral and airglow emissions. The satellite will transmit continuously in a simple FM/FSK mode suitable for easy reduction of data by interested auroral observers.

Distant television photography of terrestrial auroras is another technique of potentially great value and currently within the state-of-the-art. One can easily envisage a TV base from the moon or - more simply - from a geostationary satellite so as to photograph both Aurora Borealis and Aurora Australis. Alternatively, with a high-inclination high-altitude satellite one could utilize an elliptical orbit to produce essentially a "zoom-lens" effect with varying spatial resolution.

It may reasonably be expected then, that principal future progress in space-borne studies or auroral emissions will be in:

(a) TV studies;

(b) studies of UV and other "obscured" emissions;

(c) morphological or synoptic studies, and

(d) coordinated studies in which related experiments are performed on the single satellite.

5. ACKNOWLEDGEMENTS

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FIGURE CAPTIONS

Figure 1: Use of a magnetically-oriented spacecraft to study simultaneously both auroral "cause" (i.e. precipitated particles) and "effect" (i.e. emitted light). Note that the geomagnetic field constrains and guides the charged particles as they spiral in to hit the atmosphere. Gravitationally-oriented satellites lack this advantage, although they have other advantages, e.g. they can view near horizon for brighter emissions and for altitude data.

Figure 2: Simultaneous observation of an aurora and some of the precipitated particles that caused it. Note the approach to isotropy of trapped and precipitated particles, as well as the rapid decrease in intensity of both at higher latitudes, i.e. above the "boundary of trapping" (from O'Brien, 1964).

Figure 3: Samples of auroras detected by Injun 3. Note the decrease of intensity to the airglow plateau (from O'Brien and Taylor, 1964).

Figure 4: Comparison of Injun 3 3914A photometer data with Vestine's auroral isochasms. The satellite data came from some fifty northern hemisphere nighttime new-moon passes early in 1963 (from O'Brien and Taylor, 1964).

Figure 5: Individual measurements of 3914A intensity as a function of latitude during some fifty passes of Injun 3. The accuracy of each datum point is very much better than the scatter of points at a given latitude. Note that there is always finite emission in the auroral zone (from O'Brien and Taylor, 1964).

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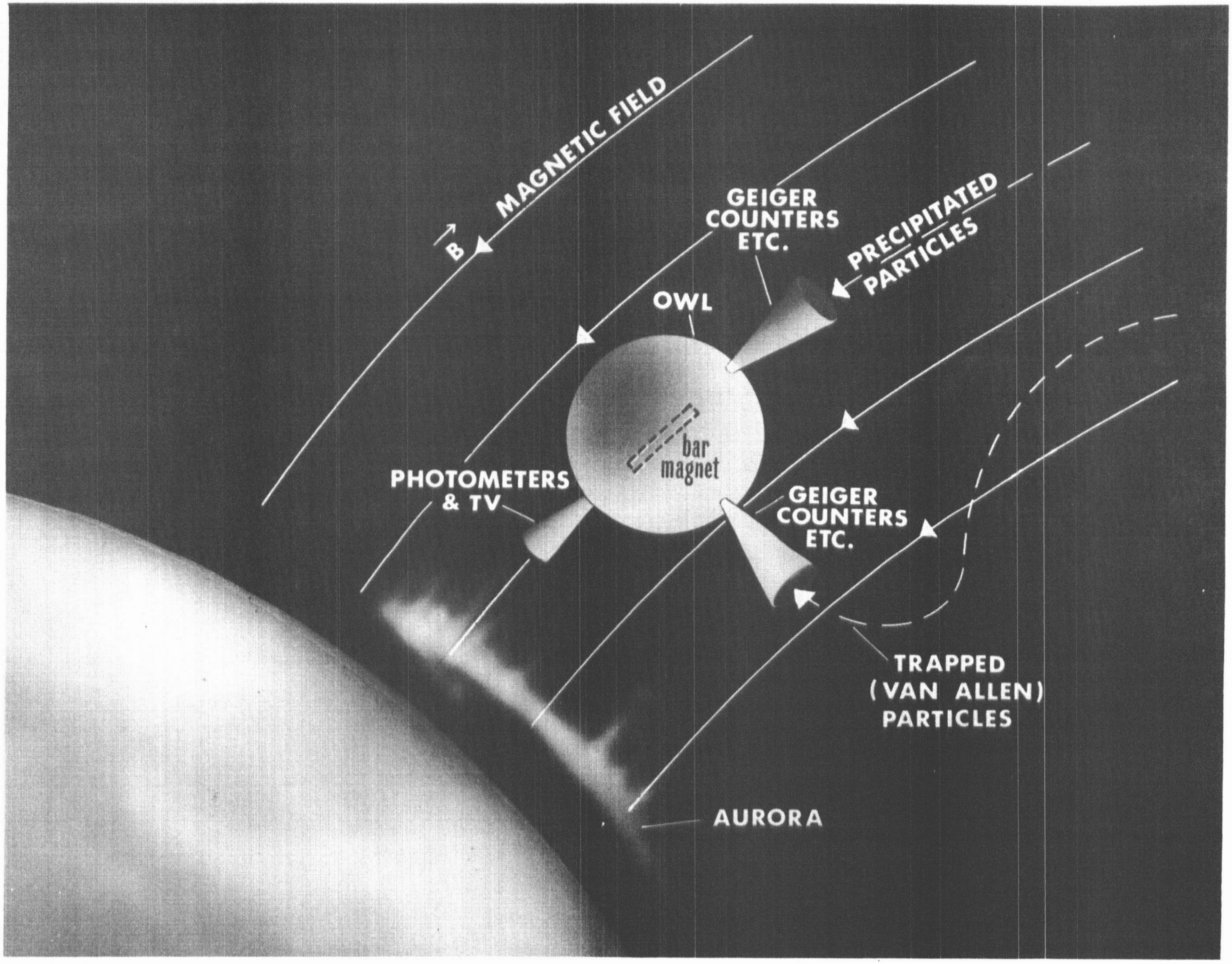
TABLE 1

Unmanned Spacecraft Used In
Airglow/Aurora Studies

SPACECRAFT	OPERATIONAL LIFE	INSTRUMENTS	AIRGLOW	AURORA	REFERENCE
Injun I	June 29, 1961 - January 1963	5577A Photometer	Obscured		O'Brien [1964]
USAF	Nov. 6, 1962 (two orbits)	5577A Photometer	√	X	Elliott, et al., [1963, private communication]
		6300A Photometer	√	X	
Injun 3	December 1962 - September 1963 (Complete lifetime)	5577A Photometer	√	√	O'Brien and Taylor [1964]
		3914A Photometer	X	√	
		5577A Photometer	√	√	
OSO-B	February 1965 - 1966 (Complete lifetime)	2 prs. Photometers (4300 ± 500); (5200 ± 500)A	√	X	Ney [Private communication]
OGO-II	October 14, 1965 - October 24, 1965 (≈40 hrs. operational with ≈2 hrs. in eclipse).	6300A Photometer	√	√	Reed and Blamont [1966]
		Multiple emission Photometer	√	√	
		UV ion chambers (1230-1350A, Lyα)	√	X	Mange [Private communication]
		UV spectrometer (1100-3400A)	√	X	Barth and Wallace [Private communication]
USAF	November 1965 (125 auroral-zone crossings)	2-3914A Photometers	X	√	Evans, et al., [1966]
		2-UV Photometers (≈1300-1800)A	√	√	

√ = indicates this phenomenon could be detected in the experiment.

X = indicates phenomenon could not be detected in the experiment.



$\vec{B}$
MAGNETIC FIELD
GEIGER
COUNTERS
ETC.
PRECIPITATED
PARTICLES
OWL
bar
magnet
PHOTOMETERS
& TV
GEIGER
COUNTERS
ETC.
TRAPPED
(VAN ALLEN)
PARTICLES
AURORA

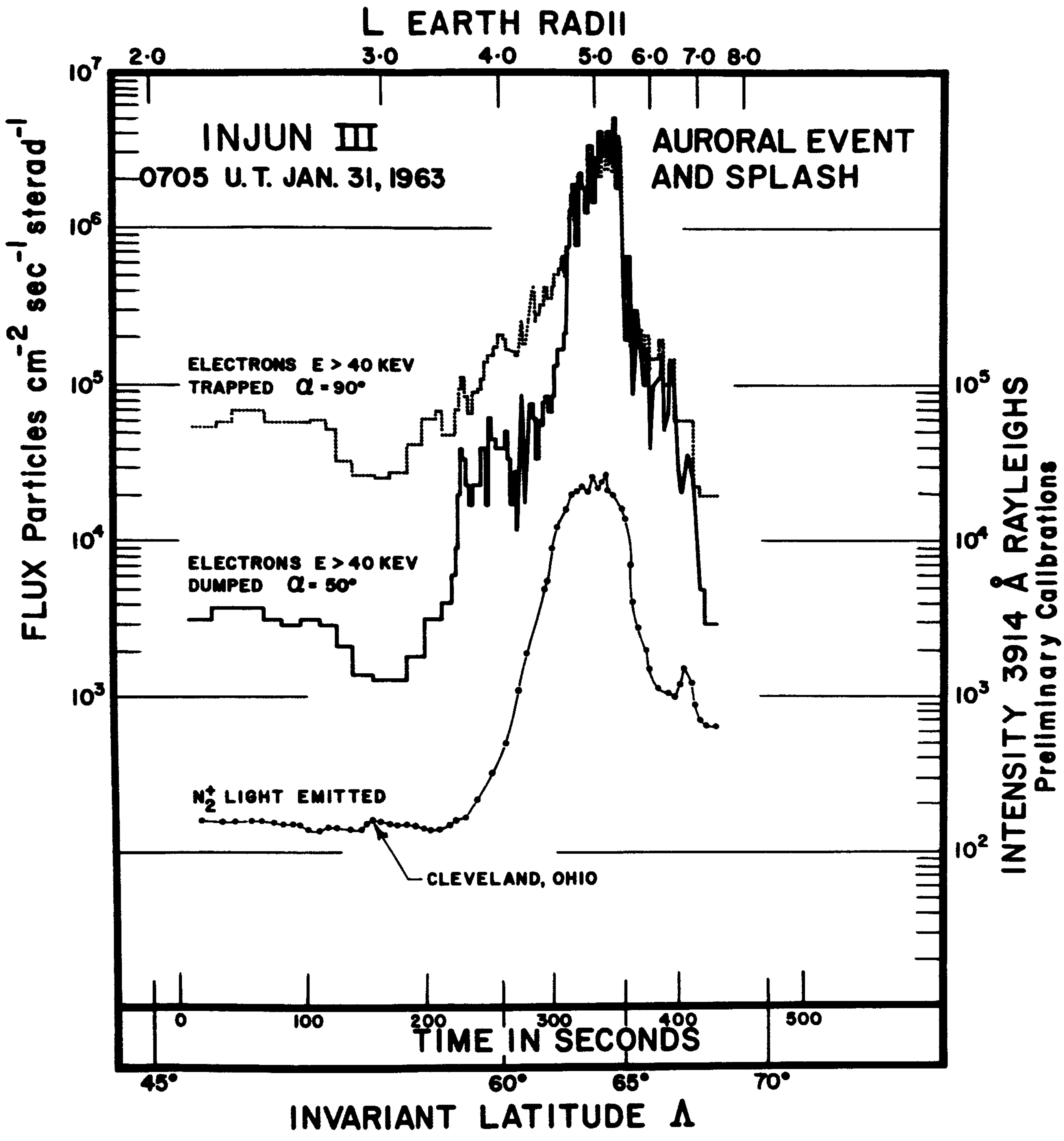

L EARTH RADII
2·0
3·0
4·0
5·0
6·0
7·0
8·0
INJUN III
0705 U.T. JAN. 31, 1963
AURORAL EVENT
AND SPLASH
FLUX Particles cm⁻² sec⁻¹ sterad⁻¹
ELECTRONS E > 40 KEV
TRAPPED α = 90°
ELECTRONS E > 40 KEV
DUMPED α = 50°
N₂⁺ LIGHT EMITTED
CLEVELAND, OHIO
INTENSITY 3914 Å RAYLEIGHS
Preliminary Calibrations
0
100
200
300
400
500
TIME IN SECONDS
45°
60°
65°
70°
INVARIANT LATITUDE Λ

FIGURE II-2

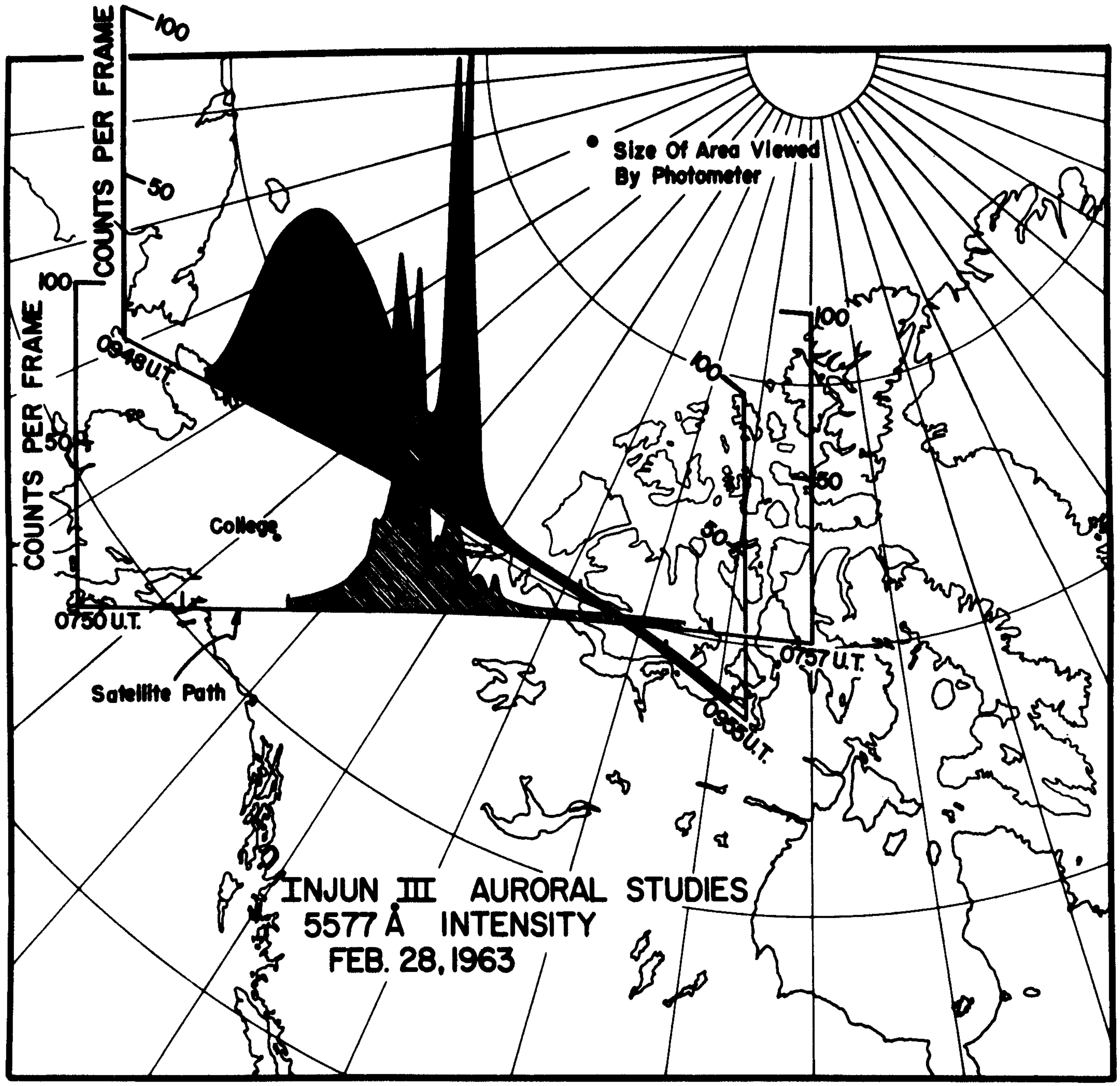

INJUN III AURORAL STUDIES
5577 Å INTENSITY
FEB. 28, 1963
Size Of Area Viewed By Photometer
COUNTS PER FRAME
100
50
COUNTS PER FRAME
100
50
0948 U.T.
0750 U.T.
0757 U.T.
0955 U.T.
College
Satellite Path

FIGURE II - 3

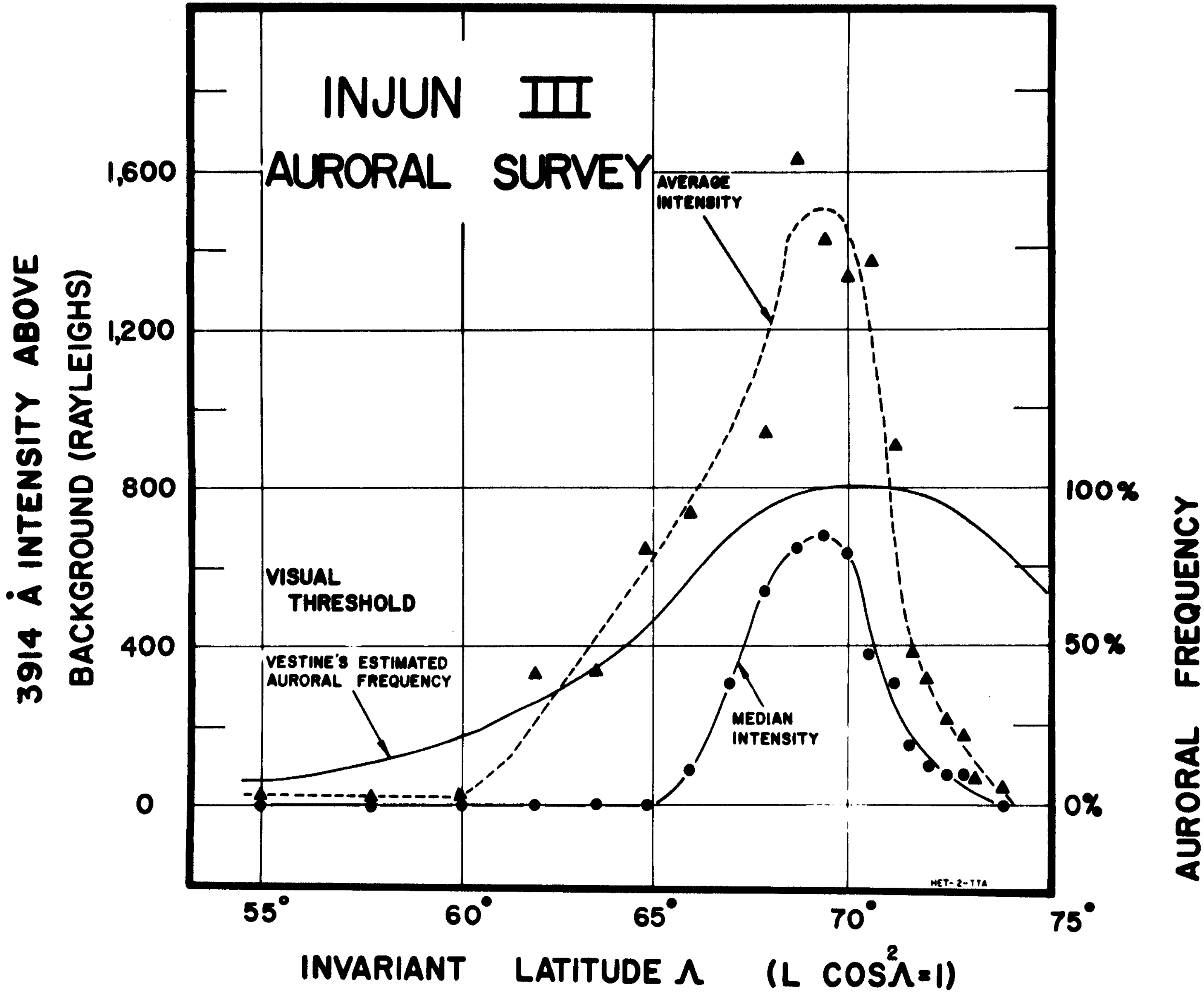

INJUN III
AURORAL SURVEY
AVERAGE INTENSITY
VISUAL THRESHOLD
VESTINE'S ESTIMATED AURORAL FREQUENCY
MEDIAN INTENSITY
1,600
1,200
800
400
0
100%
50%
0%
3914 Å INTENSITY ABOVE BACKGROUND (RAYLEIGHS)
AURORAL FREQUENCY
55°
60°
65°
70°
75°
INVARIANT LATITUDE Λ (L COS²Λ=1)
HET-2-TTA

FIGURE II - 4

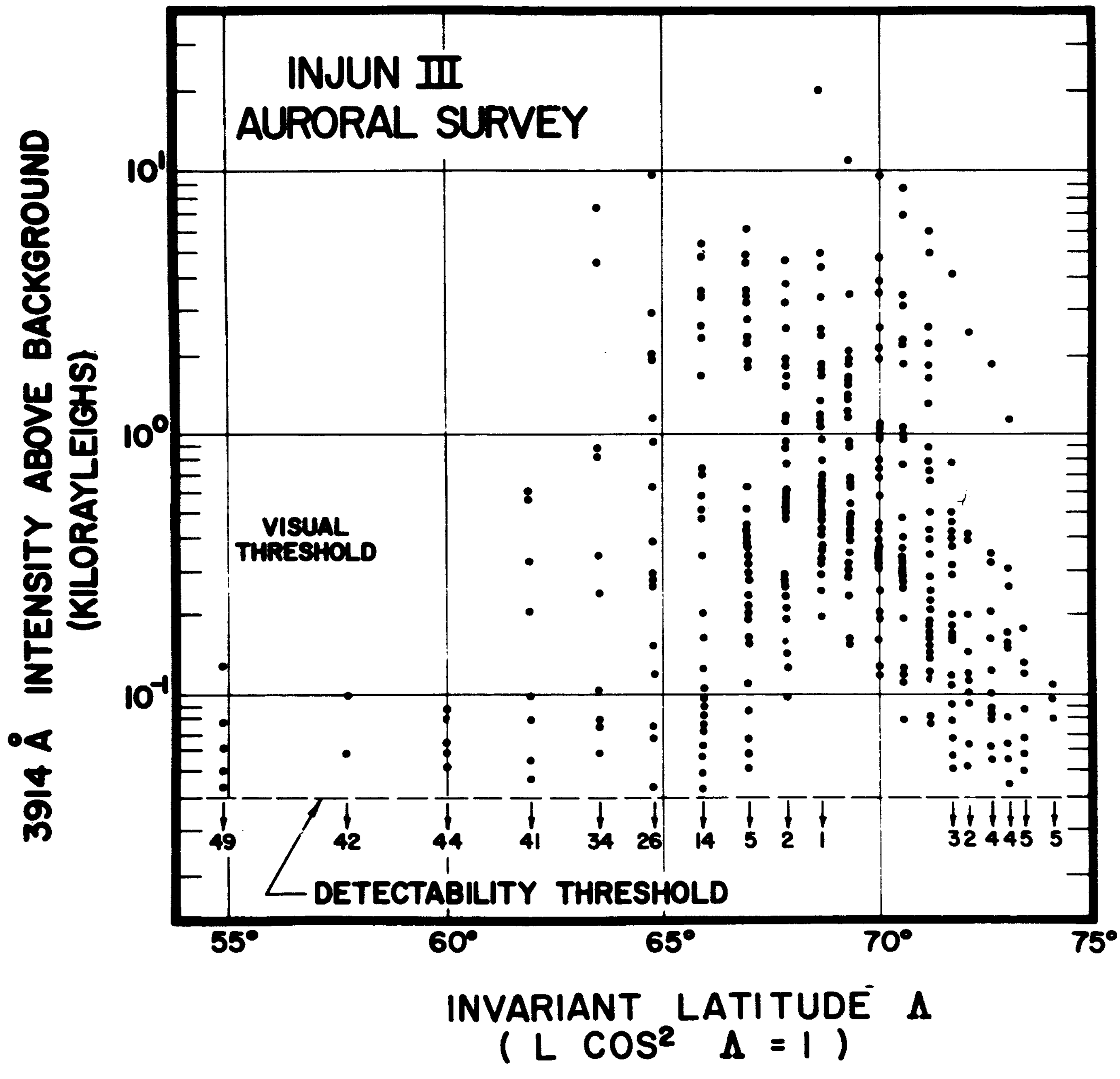

INJUN III
AURORAL SURVEY
10^1
10^0
10^{-1}
VISUAL THRESHOLD
DETECTABILITY THRESHOLD
49
42
44
41
34
26
14
5
2
1
3 2 4 4 5 5
55°
60°
65°
70°
75°
3914 Å INTENSITY ABOVE BACKGROUND (KILORAYLEIGHS)
INVARIANT LATITUDE Λ
(L COS² Λ = 1)

FIGURE II - 5